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STUDIES OF DISPLAY SYMBOL LEGIBILITY

Part III: Line Scan Orientation Effects

MAY 1966

B. Botha
D. Shurtleff
M. Young

Prepared for
DEPUTY FOR ENGINEERING AND TECHNOLOGY
DECISION SCIENCES LABORATORY
ELECTRONIC SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
L. G. Hanscom Field, Bedford, Massachusetts



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Project 7030

Prepared by

THE MITRE CORPORATION
Bedford, Massachusetts

Contract AF19(628)-5165

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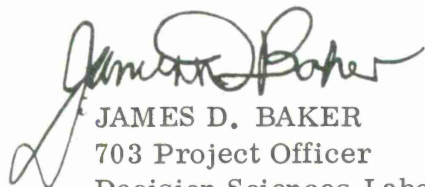
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FOREWORD

This report is one of a series describing symbol legibility for television display. Additional information on this topic may be found in the following reports: "Studies of Display Symbol Legibility: The Effects of Line Construction, Exposure Time, and Stroke Width," by B. Botha and D. Shurtleff, The MITRE Corp., Bedford, Mass., ESD-TDR-63-249, February 1963 and "Studies of Display Symbol Legibility, II: The Effects of the Ratio of Width of Inactive to Active Elements Within a TV Scan Line and the Scan Pattern used in Symbol Construction," by B. Botha and D. Shurtleff, The MITRE Corp., Bedford, Mass., ESD-TDR-63-440, July 1963.

REVIEW AND APPROVAL

This Technical Report has been reviewed and is approved.



JAMES D. BAKER
703 Project Officer
Decision Sciences Laboratory



ROY MORGAN
Colonel, USAF
Director, Decision Sciences Laboratory

ABSTRACT

This report delineates effects upon letter legibility produced by horizontal, oblique, and vertical simulated linear TV scan lines. Horizontal lines were parallel to letter bases; the angle between letter bases and oblique lines was 45 degrees; and vertical lines were perpendicular to the letter bases.

The results indicate that letter legibility, as measured by response accuracy and letter identification reaction time, is not affected to any significant degree by the scan line angle. In general, the oblique lines yielded the best legibility scores particularly for brief letter exposure times.

The main finding of the study was that certain letters remain highly legible regardless of the scan line orientation used for their presentation, and, therefore, are uniquely suitable for TV display.

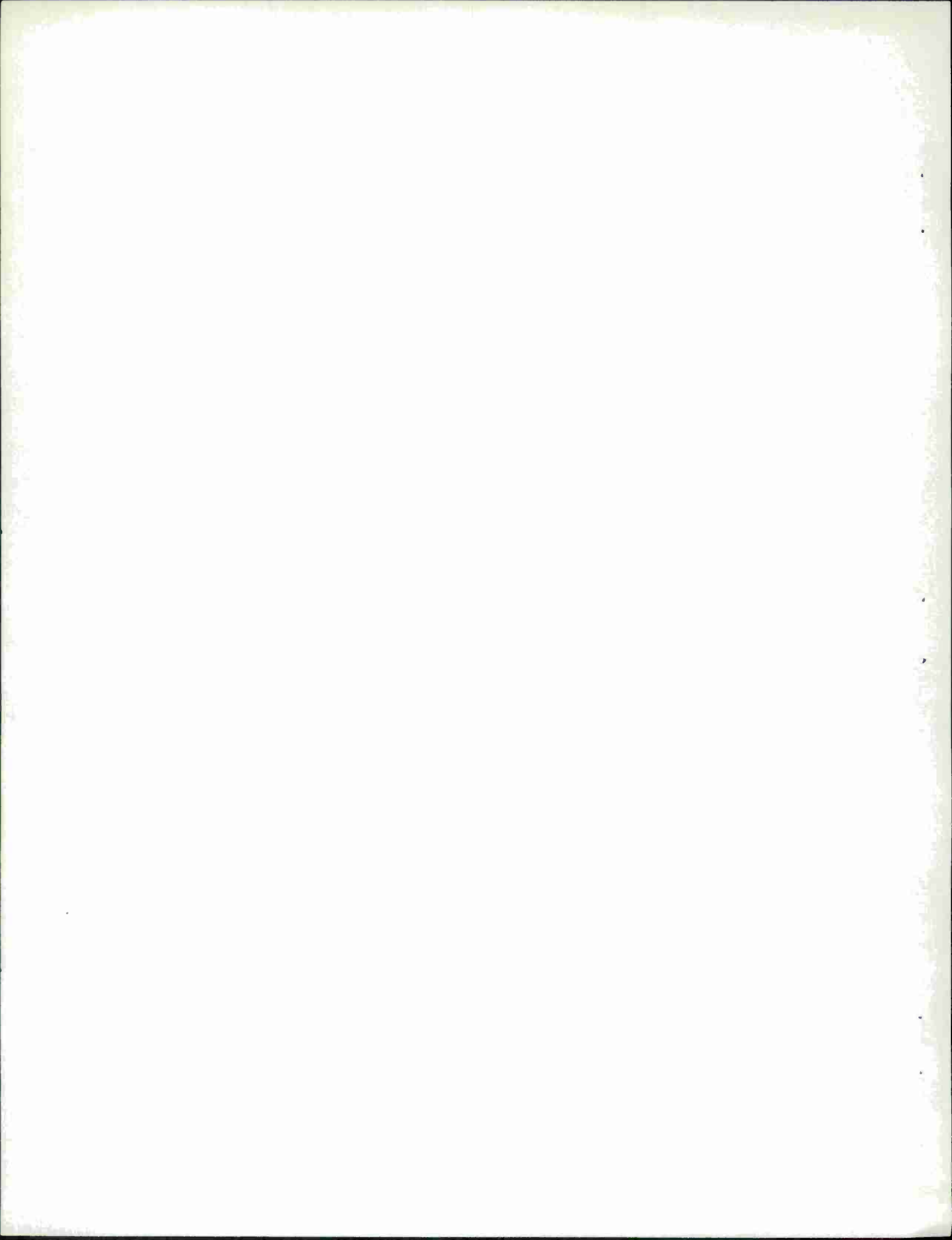


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SECTION I

INTRODUCTION

The present study is a continuation of previous work^[1,2] which is concerned with an evaluation of the effects on letter legibility by factors unique to TV displays. Of interest in this investigation are the effects that different orientations of simulated linear TV scan lines have upon legibility. It seemed a reasonable notion that scan line orientation might affect letter legibility, since changes in the angle of scanning relative to a letter would effectively produce associated changes in the geometry of the displayed letter image. Furthermore, because of the numerous horizontal and vertical components of standard alphabetic capital letters, it might be assumed that better legibility would be achieved by a scan line orientation of 45 degrees (with respect to the base of the letters) than by either horizontal or vertical lines.

Three orientations of simulated linear TV scan lines were used: horizontal, oblique, and vertical. The legibility of letters constructed by the three orientations was determined by measuring the percentage of correct responses at letter exposure times of 0.03 and 0.003 seconds, and for resolutions of 22 and 49 lines per inch (corresponding to 5 and 11 lines per symbol height for the horizontal line scan). The exposure times and resolutions used in the current study were identical to those of a study^[1] that had demonstrated a significant interaction between those values of exposure and resolution and other parameters of letter legibility. For this reason they might offer a more sensitive evaluation of the effects of line orientation on legibility than would be obtained by using single values for exposure and resolution.

SECTION II PROCEDURE

APPARATUS EMPLOYED

Twelve subjects with normal vision served in the study. The stimuli (capital letters) and apparatus were the same as described in Reference 2. (Letters were presented tachistoscopically, and film negatives with alternate opaque and transparent lines were used to simulate TV scanning.) The 5- and 11-line negatives with a 1:1 ratio of opaque to transparent strips^[2] were placed so that the grid lines were horizontal for the 0-degree orientation. Therefore, they were parallel with the base of the letters. For the 45-degree orientation, the grid lines made an angle of 45 degrees with the base of the letters; and for the 90-degree orientation, the grid lines made an angle of 90 degrees with the base of the letters.

EXPERIMENTAL DESIGN

A mixed experimental design was used in which each subject was assigned to only one condition of line orientation, but to all conditions of exposure time and resolution. Group I (four subjects) was shown letters constructed by the 0-degree line orientation, Group II (four subjects) was shown letters constructed by the 45-degree line orientation, and Group III (four subjects) was shown letters constructed by the 90-degree line orientation.

EMPLOYMENT OF SUBJECTS

Each subject had a total of eight experimental sessions. Each session consisted of 130 presentations of the 26 alphabetic letters, each of which was repeated 5 times in random sequence. In the first four sessions, a subject

viewed the letters at a given line orientation at 0.03 seconds and at 0.003 seconds for each of the two resolutions of 22 and 49 lines per inch. The order of the sessions was randomly determined. The last four sessions were identical to the first four, except that the order of presentation was reversed. The results are based upon responses made in the last four sessions because they represent the expected performance of well-practiced subjects. Both accuracy and reaction time for letter identification were recorded. The procedure for presenting stimuli, recording responses, and instructing the subjects was the same as described in Reference 2. The subject's task was to call out the name of the letter as quickly as possible, and the instructions gave equal emphasis to both speed and accuracy in identification of letters. Additional details of the instructions can be found in Reference 1.

SECTION III

RESULTS

RESPONSE ACCURACY

The accuracy with which the subjects were able to identify letters at each orientation of the scan lines and at each of the two exposure times and resolutions is shown in Figure 1 which indicates a nearly perfect letter identification accuracy for all orientations and resolution values of the scan lines for the 0.03 second exposure. It is apparent that reducing the exposure time of the letters to 0.003 seconds impaired the accuracy of letter identification for all groups, but there was a tendency for the amount of impairment to be greater for Groups I and III than for Group II.

Data Distribution

The distribution of the accuracy data was highly skewed; and for this reason, standard analysis of variance techniques could not be used. Therefore, the significance of the data was determined by a nonparametric analysis of variance.^[3] Since this test is only a one-way analysis of variance, separate analyses of the differences among the three groups were performed for each combination of exposure time and resolution. The results of these analyses are presented in Table I. As this table shows, none of the differences among the groups was significant.

Rank Order Correlations (Rho)

Although response accuracy was similar for each of the three line orientations, there was the possibility that some letters would be identified more readily with one orientation than with another, and also that the kinds of inter-letter confusions would differ for the three groups. In order to

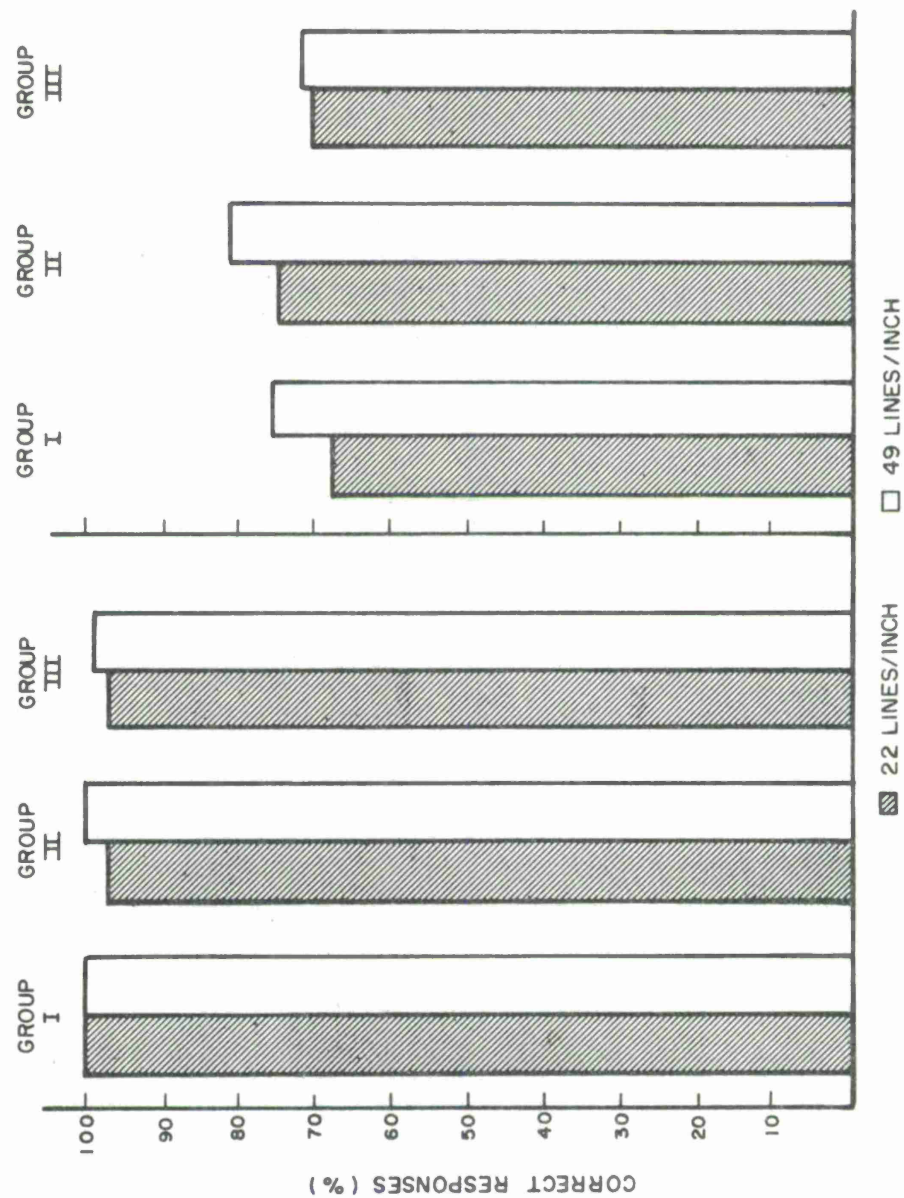


Figure 1. Letter Response Accuracy

Table I
Variance of Group Error Scores

Lines/In.	Seconds			
	0.03		0.003	
	H	P	H	P
22	1.1586	> 0.10	0.1250	> 0.10
49	3.500	> 0.10	2.7971	> 0.10

determine if the ranking of letters from the most legible to the least legible (highest and lowest accuracy scores) was similar for all line orientations, rank order correlations (ρ) among each of the three groups were calculated. The calculated ρ s among groups were: 0 and 45 degrees, $\rho = 0.47$; 0 and 90 degrees, $\rho = 0.50$; 45 and 90 degrees, $\rho = 0.41$. The correlation coefficients between 0 and 45 degrees and between 0 and 90 degrees were significant at the 0.01 level, and the correlation coefficient between 45 and 90 degrees was significant at the 0.05 level.

Inter-Letter Confusions

Inter-letter confusions for each of the line orientations were determined by the construction of confusion matrices, which indicated where, and to what extent, inter-letter confusions occurred. A summary of the most prominent inter-letter confusions is presented in Table II, which shows only those confusions that accounted for two percent or more of the total number of errors made by all subjects within each line orientation condition. Table II shows errors made only at the 0.003-second exposure, since the total number of errors for all groups at the 0.03-second exposure was negligible. The confusions indicated by an asterisk indicate inter-letter confusions that are

unique to a particular line orientation; the confusions indicated by a plus sign are those common to all line orientations; and the unmarked confusions occur for two orientations. Table II shows that the only confusion common to all three groups was between Q and O.

Table II
Major Inter-letter Confusions

LINE ORIENTATION								
Group I (0 degrees)			Group II (45 degrees)			Group III (90 degrees)		
Letter	Response	Percent Error	Letter	Response	Percent Error	Letter	Response	Percent Error
* I	J	3.0	* H	N	3.5	* F	I	2.5
* O	Q	3.7	* I	T	2.1	* G	O	2.0
* F	P	2.0	O	G	2.1	E	F	3.2
L	I	4.0	T	I	2.6	L	I	3.0
O	G	2.0	V	Y	2.1	T	I	3.0
E	F	2.0	+ Q	O	2.6	V	Y	2.0
+ Q	O	2.7				+ Q	O	2.5

REACTION TIMES

The reaction times for letter identifications for the three line orientations (Groups I, II, and III) at the two values of resolution and exposure time are shown in Figure 2. Both A and B of Figure 2 indicate that reaction time was fastest for Group II. Although not so apparent from the figure, a reduction of exposure time resulted in a smaller increase in reaction time for this group than for the others. In particular, Group I shows a substantial increase in reaction time when exposure time was decreased from 0.03 to 0.003 seconds.

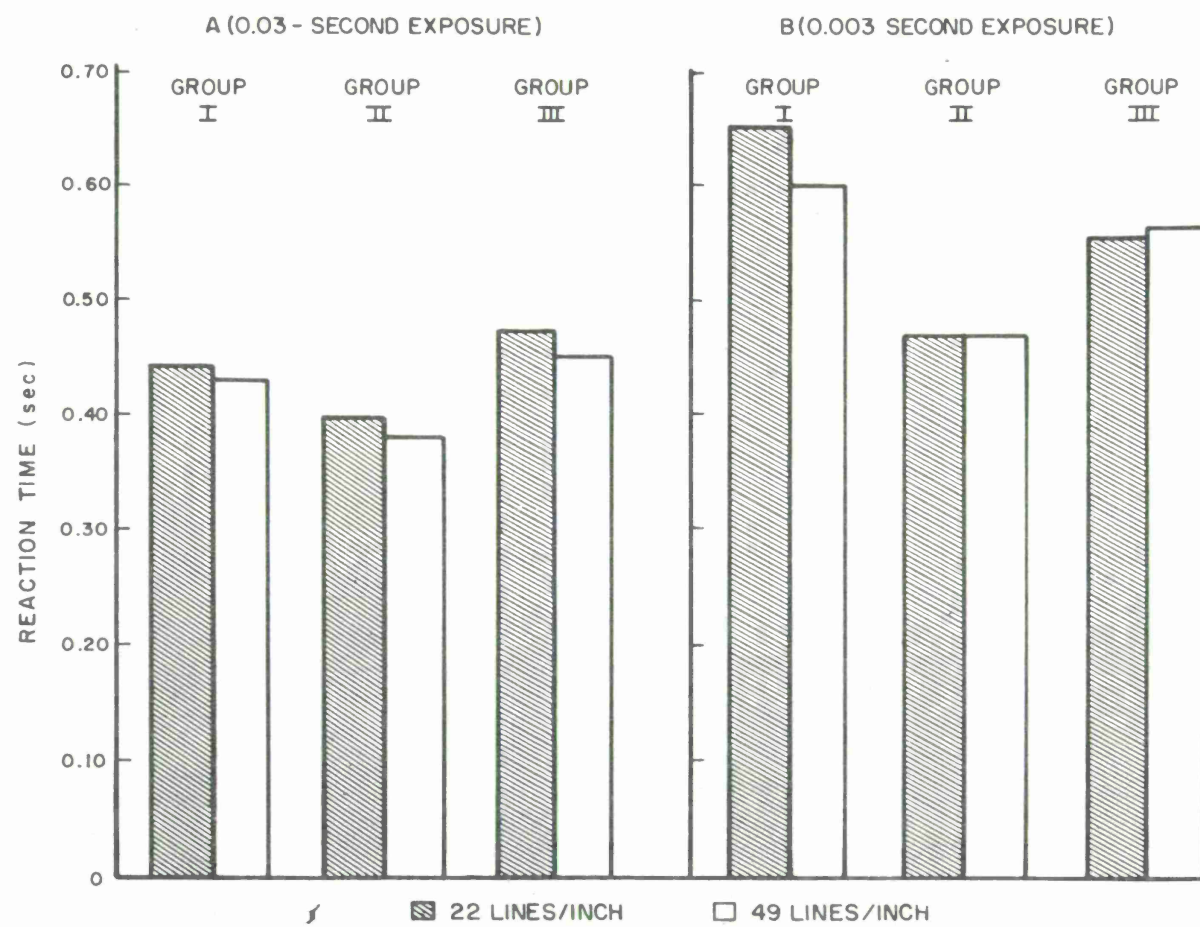


Figure 2. Identification Reaction Times

Analysis of Variance

The reaction time data were submitted to an analysis of variance appropriate for a mixed design, and the results of this analysis are presented in Table III, which shows that the differences noted in reaction times among groups were not significant. Reducing the exposure time from 0.03 to 0.003 second resulted in a significant increase in reaction time, although, as the significant interaction between exposure time and groups indicates, the effect of exposure time on reaction time depends upon the line orientation used. Figure 2 shows that the reaction time for letter identification for the 45-degree line orientation was not affected as much by a decrease in exposure time as were the reaction times for letter identifications for each of the other two line orientations.

LINE RESOLUTION

The finding that the 5-line resolution generally yielded lower accuracy scores and higher reaction time scores than the 11-line resolution agrees with results previously reported.^[1] Also in agreement with those results is the finding that accuracy of letter identification was poorer and reaction times higher for a letter exposure time of 0.003 second than for a letter exposure of 0.03 second.

Table III
Reaction Time Variance

Between Groups	Sum of Squares	Degrees of Freedom	Mean Square	F	Probability of F
Subjects	2180.05	11			
Groups(G)	876.13	2	438.06	3.02	NS
Error	1303.92	9	144.89		
Within Groups	2447.70	36			
Exposure(E)	1646.7	1	1646.70	102.98	0.01
Line(L)	55.42	1	55.42	3.47	NS
E x L	4.0	1	4.0		NS
E x G	277.99	2	138.99	8.69	0.01
L x G	4.03	2	2.01		NS
E x L x G	27.65	2	13.82		NS
Error	431.91	27	15.99		
Total	4627.75	47			

SECTION IV

DISCUSSION

NUMBER OF SUBJECTS

The data obtained offer no conclusive evidence that changing the angle of linear scan lines relative to capital alphabetic symbology will significantly affect letter legibility. However, in view of the tendency for legibility to be best for the 45-degree orientation of scan lines, one might ask whether the significance of this effect could be demonstrated by the inclusion of more subjects in the study. Running more subjects would not be worth the additional time and effort required, as it is unlikely that the additional data would alter the findings among line orientations, particularly at a letter exposure of 0.03 second.




LEGIBILITY RANKING OF LETTERS

Probably the most important finding of this study was the significant correlation among the ranking of letters, from the most to the least legible, for the three line orientations. This suggests that, for television display use, it would be possible to select a subset of letters which are maximally legible regardless of the scan line orientation used in their construction. For example, in Spanrad displays, ^[4] letters are likely to be shown in a number of different orientations. This means that sometimes they will be constructed by either horizontal, oblique, or vertical scan lines. Consequently, there might be some advantage in using letters which retain a high degree of legibility under a variety of scan line constructions for conveying important display information. In the present study, some of the most legible letters found were C, M, U, and W.

LETTER RECOGNITION PROCESSES

While most of the findings were inconclusive, the study raises some general questions which are fundamental to understanding the perceptual processes involved in letter recognition. Some of these questions were: What perceptual cues enable one to distinguish a letter from any other; how does one determine what these cues are; how can the degree of similarity and dissimilarity among letters be measured; and how does degradation (scan line construction) alter letter perceptibility?

Components

For example, for the alphabet used in this study, only the bottom horizontal component distinguishes E from F. (This is true for many standard alphabets.) Therefore, discrimination between E and F depends upon detection of that component. This means that the question of letter perceptibility becomes one of determining whether such components are detectable more readily when the scanning is horizontal, oblique, or vertical. More basically, if a given area of a component is deleted by a linear scan line technique (as in high speed printer techniques), is there a difference where the deletion occurs? If the deleted area remains constant, which is the most perceptible: (a) , (b) , or (c)  ? In this example, the data suggest that (c) might be the most perceptible since there was an absence of a major E-F confusion for the 45-degree line orientation, while E-F confusions were present for the other two orientations.

Construction of Letters

It should be recognized that, on the basis of this data, one cannot evaluate which of the constructions is the most perceptible since there was no control over the absolute area of the component exposed by each line orientation. It does suggest, however, that some constructions are more

perceptible than others, and it appears that different construction techniques (in which parts of letters are deleted) will reduce legibility, particularly when the discrimination between two letters is based upon the detection of a single letter component.

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1. B. Botha and D. Shurtleff, "Studies of Display Symbol Legibility: The Effects of Line Construction, Exposure Time, and Stroke Width," The MITRE Corp., Bedford, Mass., ESD-TR-63-249, February 1963.
2. B. Botha and D. Shurtleff, "Studies of Display Symbol Legibility, II: The Effects of the Ratio of Widths of Inactive to Active Elements Within a TV Scan Line and the Scan Pattern Used in Symbol Construction," The MITRE Corp., Bedford, Mass., ESD-TR-63-440, July 1963.
3. S. Siegel, Nonparametric Statistics for the Behavioral Sciences, McGraw Hill, New York, New York, 1956, pp. 184-188.
4. G. Rowland and D. Cornog, "Selected Alphanumeric Characters for Closed-Circuit Television Displays," Report 21, Project M, CAA Contract C13, ca-646, July 1958.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Systems Displays Display Design Psychology Human Characteristics Legibility Readability						

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